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Forest Health Management

BIOLOGICAL EVALUATION
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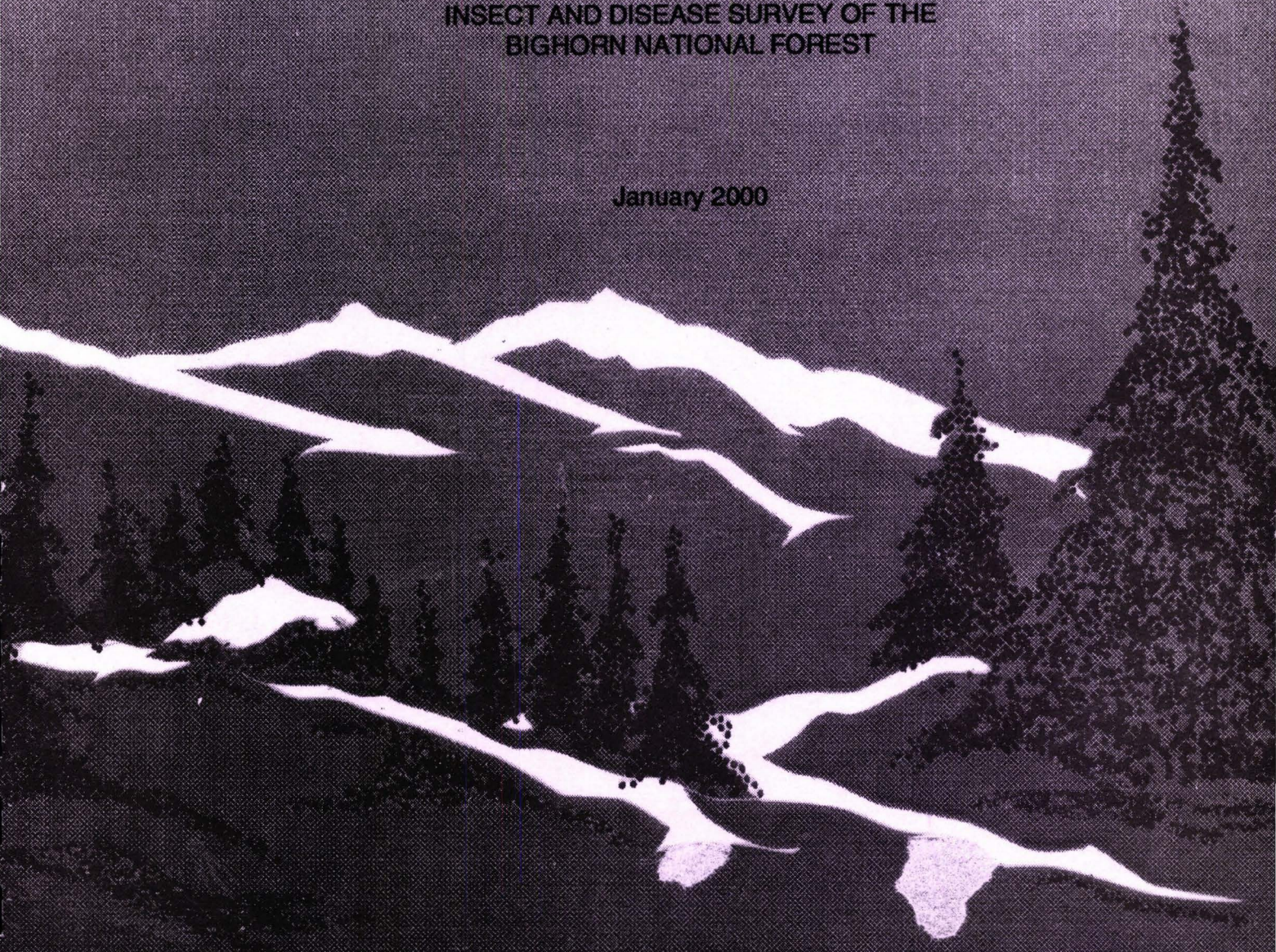
INSECT AND DISEASE SURVEY OF THE
BIGHORN NATIONAL FOREST

January 2000



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BIOLOGICAL EVALUATION
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INSECT AND DISEASE SURVEY OF THE BIGHORN NATIONAL FOREST

January 2000

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ABSTRACT

Bighorn National Forest managers are preparing to revise the forest plan starting in the year 2000. An integral portion of the forest plant includes the effects of forest insects and diseases on the forest management objectives. This biological evaluation provides a discussion of prominent insects and diseases of the forest and results from ground surveys conducted during the summer of 1999. Forest Health Management surveyed 17.5 miles of chain-wide survey transects distributed throughout forested stands to assess the current insect and disease damages in the Bighorn National Forest. Dying or recently dead trees along the lines were examined for bark beetle activity. Variable-radius plots were used every 10 chains to rate dwarf mistletoe and rust diseases on pines. Of the forested area surveyed, approximately 60 percent was lodgepole pine, 25 percent Engelmann spruce, 8 percent subalpine fir, 5 percent limber pine, and minor components of Douglas-fir, juniper, and quaking aspen. Spruce beetle and western balsam bark beetle and caused most of the damage in the spruce-fir forest type. Total activity level for spruce beetle was more than 2 trees killed per acre over the last 3 years. Total activity level for the western balsam bark beetle was slightly less than 2 trees per acre killed over the last 3 years. Mountain pine beetle activity was at an endemic level with approximately 1.5 trees killed per acre in the lodgepole pine forest type over the last 3 years. However, mountain pine beetle was found to be active in the ponderosa pine forest type along the eastern slope of the Bighorn Mountains and in the limber pine forest type in Ten Sleep Canyon. Comandra blister rust and dwarf mistletoe diseases have infected 8 percent and 28 percent, respectively, of the lodgepole pine in the area surveyed. The Comandra blister rust incidence is high; an average severity rating for these trees indicates that most are top-killed and dying. The average dwarf mistletoe rating for infected trees was 3 suggesting moderate infections levels. Moderate infection levels of white pine blister rust were also found on the limber pine in Ten Sleep Canyon. Recommendations are to use prescribed fires, thinnings, and overstory removal depending on forest cover types. This will promote more pine and aspen regeneration and help protect the sites from extensive insect and disease outbreaks.

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INTRODUCTION AND MANAGEMENT OBJECTIVES

Bighorn National Forest managers are preparing to revise the forest plan during 2000. An integral portion of the forest plant includes the effects of forest insects and diseases on the forest management objectives.

Several insects and diseases have historically impacted forest management objectives on the Bighorn National Forest. Prominent insect and disease problems of the spruce-fir and Douglas-fir cover types are spruce beetle (*Dendroctonus rufipennis)*, Douglas-fir beetle (*Dendroctonus pseudotsugae)*, and western spruce budworm (*Choristoneura occidentalis)*. Another forest health problem, fir decline, is currently being investigated in the central Rocky Mountains and in this area. Causal agents of this decline include western balsam bark beetle *(Dryocoetes confusus)* activity and root diseases. Although moderate levels of western spruce budworm defoliation and Douglas-fir beetle have been recorded in the Bighorns National Forest, these insects were not observed in this survey.

The pine cover types are susceptible to mountain pine beetle (*Dendroctonus ponderosae*), pine engraver beetles (*Ips*), and several diseases. Comandra blister rust (*Cronartium comandrae)* and dwarf mistletoe disease (*Arceuthobium americanum)* occur at high incidence levels in lodgepole pine stands throughout Wyoming. Outbreaks of a needlecast disease (*Lophodermella* spp.*)* on lodgepole pine have also occurred on the Bighorn National Forest. Limber pine also has been noticeably declining in the Bighorn National Forest. This decline may be caused by one or several factors such as mountain pine beetle, white pine blister rust (*Cronartium ribicola)*, dwarf mistletoe *(Arceuthobium cyanocarpum)*, and needlecast disease (*Dothistroma septospora)*.

Each of these insects, diseases, and types of decline may impact management objectives for the Bighorn National Forest. Spruce beetle and fir decline will be discussed in detail as to their ecology and management. Mountain pine beetle and diseases of pines (rusts, dwarf mistletoes, and needlecast diseases) will also be discussed.

ECOLOGY & MANAGEMENT OF FOREST INSECTS AND DISEASES IN THE BIGHRON NATIONAL FOREST

Spruce Beetle

The most important threat to spruce is the spruce beetle. The spruce beetle is a native bark beetle that occurs throughout the range of spruce in North America. The beetle is typically found at endemic levels in downed trees and large pieces of slash. Epidemic populations most often occur after large disturbances, such as windthrows, create a large volume of suitable host material for the beetle to build up in. Once populations reach an epidemic stage, all sizes of standing green spruce can be attacked except for

reproduction. While all sizes can be attacked, it is most often focused on the larger trees within a stand. Much like other insect and disease disturbance agents, it can cause dramatic changes in stand structure and composition.

The spruce beetle usually requires two years to complete a generation; in high elevations it can take three years. Adults fly, attack host trees, and lay their eggs in June and July. Larvae develop under the bark and remain there to overwinter. Larval development continues the following spring and summer, with new adults emerging in August. These adults then hibernate beneath the bark until the following June and July.

Spruce stands that are most susceptible to spruce beetle outbreaks generally have the following characteristics (Schmid and Frye 1976):

1. Are located in creek bottoms.
2. Have large diameter host trees.
3. Have high basal areas.
4. Have a large proportion of spruce in the canopy.

Thus, spruce beetle is a concern that should be noted in stands that have large mature and overmature trees. Windthrow events in or near these stands can lead to mortality of standing green trees (Schmid and Hinds 1974). Spruce beetle populations have been detected in the Medicine Wheel area in the 1970's and 1980's and were associated with blowdown trees.

Spruce beetle, unlike mountain pine beetle, is attracted, and often builds up in damaged trees. Frequently this is in windthrown/blowdown trees, however, fire-scorched trees also are susceptible. For example, Rasmussen et al. (1996) found an increased number of spruce beetles in trees that were scorched up to a certain level of damage. Once scorching exceeded 60 percent of the basal circumference girdled, trees were no longer as suitable for spruce beetle infestation. This is something to be considered when using prescribed fire. Many of the larger spruce may have bark thick enough to survive lighter prescribed burns, however, if they are scorched to a certain degree, they can be more susceptible to spruce beetle attack. Stands that contain a large number of larger, partially scorched spruce, could be centers for spruce beetle buildup and epidemics.

Mountain Pine Beetle

The most serious insect pest of pine throughout the West is the mountain pine beetle. This is a native beetle that can attack and kill all of the pine species (lodgepole, ponderosa, and limber pine) in the Bighorn National Forest. Mountain pine beetle activity has historically been relatively light and scattered; however, outbreaks have been recorded in the late 1960s and mid-1970's in both Little Bighorn River area and the eastern slopes of the Bighorn Mountains. The mountain pine beetle can reach epidemic proportions and kill significant amounts of their hosts. Although beetle behavior is well understood in relation to lodgepole pine stands, the same cannot be

said of ponderosa and limber pines. In lodgepole pine the beetle generally attacks large diameter, overstory trees, but once an epidemic starts, smaller trees can also be killed (Amman and Cole 1983). The death of overstory trees influences stand structure and composition, and can lead to stand conversion to other species.

The mountain pine beetle generally completes its life cycle in one year in lodgepole pine, although at higher elevations it can take two years (McGregor and Cole 1985). Adults typically emerge sometime in July or August and attack standing green trees. On successfully attacked trees, adults lay eggs and larvae develop under the bark. Immature larvae overwinter under the bark, then finish feeding in the spring and early summer. The developing larvae feed on the phloem, killing the tree.

Mountain pine beetle populations in lodgepole pine are in a large part dependent on the conditions present in the forest. In lodgepole pine, susceptibility to mountain pine beetle is based on three factors (Amman et al. 1977):

1. Average tree diameter,
2. Average tree age,
3. Location by latitude and elevation.

Beetle behavior in ponderosa pine is not as well understood. Forest conditions have been related to beetle susceptibility in the Black Hills of South Dakota and Wyoming. In these areas, beetle susceptibility is based on tree diameter and stand density (Schmid and Mata 1992). Average stand diameters of over 7.0 inches makes for susceptible stands. In stands that are above the minimum diameter, stands that have a basal area of over 120 square feet per acre are considered to be high risk. Stands with a basal area between 80 and 120 are moderate risk and those below 80 basal area are low risk (Schmid et al. 1994). It will be assumed that these same criteria are applicable to ponderosa pine on the Bighorn National Forest as well.

Little work has been done on mountain pine beetle behavior in limber pine. What is known is that brood production is fairly high in limber pine, indicating that beetles do very well in this species (Cerezke 1995). It will be assumed that the beetle behaves in much the same way in limber pine as in lodgepole, preferring larger diameter trees.

In both lodgepole and ponderosa pine, the factors that can be managed to reduce a stand's susceptibility to beetles include reducing average diameter and age and/or reducing stand density. Treating the stands to reduce susceptibility will provide the most long-term defense against a mountain pine beetle epidemic. In lodgepole pine, thinning is effective at reducing future losses to the mountain pine beetle (Amman et al. 1988, Cole 1989, Gibson 1989, McGregor et al. 1987). Since beetles are attracted to the largest trees initially, removal of large diameter material is also effective at reducing loss during epidemics (Cahill 1978, Cole et al. 1983, McGregor et al. 1987). Obviously, clearcutting lodgepole pine stands removes any risk of beetle infestation.

Treatments to reduce mortality in ponderosa pine include thinning stands to lower basal area or smaller diameter sizes prior to beetle outbreaks. These types of silvicultural treatments should be effective at reducing loss to the beetle in ponderosa pine. In areas where beetle populations have already become established and started increasing, sanitation harvesting can be considered. Sanitation efforts prior to the beetle flight period (July - August) may serve to reduce localized beetle spot expansion. However, sanitation harvesting on a small scale does not prevent future bark beetle migration from adjoining areas.

No work has been conducted on silvicultural treatments for reducing beetle damage in limber pine. Based on what is known from lodgepole and ponderosa pine, limber pine stands should be treated to remove the largest diameter trees and reduce stocking levels. Without any real information, these seem to be the safest options for minimizing beetle damage.

Work on how fire and fire scarred trees would effect mountain pine beetle populations has shown that this beetle does not search out and infest fire scarred trees (Rasmussen et al. 1996). In other words, the use of prescribed fire and the resulting fire scarred trees should not be any more susceptible to causing beetle population increases.

Fir Decline

The causes of subalpine fir decline are, at this point, not completely understood. What is known is that at this time, there is widespread "fir decline" taking place throughout the Rocky Mountains of Wyoming and Colorado. Large areas of subalpine fir decline have been observed on the Bighorn National Forest during recent aerial surveys and biological evaluations. Although the exact causes have not always been defined, one player in this decline appears to be the western balsam bark beetle. This beetle has been found killing subalpine fir in the western states. This beetle typically has one generation per year, with adults flying and attacking green trees in mid summer. Eggs are laid and the hatching larvae develop under the bark.

It seems that almost all size classes of subalpine fir are susceptible to beetle attack, although sapling-sized regeneration may not be affected. Lodgepole pine and Engelmann spruce and also have been occasional hosts. The impacts this beetle has as a part of "fir decline" are unknown. At this time, it is unknown if there are any stand density, diameter or composition factors that create more or less favorable conditions for beetle attack.

Other possible agents of fir decline are root diseases. This group of diseases can cause mortality, slow tree growth, and could possibly make trees more susceptible to the western balsam bark beetle. They can increase windthrow damage by weakening root systems and will hinder restocking levels by killing regeneration (Morrison 1981; Wargo and Shaw 1985). Very little root disease study has been conducted on the Bighorn National Forest and but pockets of *Armillaria* spp. and Annosus (*Heterobasidion annosum)* have been tentatively identified in the forest.

Armillaria spp. occurs on several conifer species and aspen and often acts as a decomposer of dead wood such as logging stumps. It spreads primarily through root contacts, but may also have some incidental spread by rhizomorphs or spores. Rhizomorphs are shoestring-like structures of fungal tissue that grow through the soils and infect new roots. This fungus is often called the 'shoe-string' fungus. *Armillaria* may also produce mushrooms at the base of trees after early winter storms in September and October. These mushrooms release spores that may start new infection centers in the forest (Morrison 1981).

Annosus root disease is common in fir stands in the Rocky Mountain Region. The fungus spreads by root contacts, root grafts, and spores. Fungal conks produced in stumps and at the base of dead trees will release wind-borne spores that infect fresh cut surfaces and wounds (Johnson 1985).

Root disease centers appear as a large circular area with several dead and dying trees, and perhaps blown-over trees that have broken at the root collar. Young seedlings and saplings will also be dead if they are growing next to an infected stump. Surrounding trees will have thin crowns, off-color foliage, resinous bases and root collars, perhaps a stress cone crop, and declining growth (Shaw and Kile 1991).

Possible controls for root disease are to favor other resistant tree species, usually lodgepole pine in this area. When necessary to cut root disease-infected trees, a 30 - 50 foot buffer around the disease center should also be cut to prevent the disease from spreading through stumps in the stand. If the root disease is *Annosus*, then borax may be applied to fresh cut stumps to make the stump uninhabitable by fungal spores.

Comandra blister rust disease

Comandra blister rust is the one of the most damaging disease agents of lodgepole pine in Wyoming (Mielke 1957). This rust fungus may also infect ponderosa pine in the Bighorn Mountains. High levels of Comandra blister rust in the lodgepole pine may then promote infection to nearby ponderosa pine stands of the area.

Rust fungi frequently occur with dwarf mistletoes but it is unknown if either disease makes the tree more susceptible to infection by the other disease (Schaffer et al. 1983). Also rust and dwarf mistletoe diseases may predispose the pines to mountain pine beetle attack. When bark beetle populations build up in disease-stressed trees, then the beetles can attack and kill nearby healthy trees.

The rust produces girdling cankers on pine tree stems. These cankers cause top-kill of the trees and significantly alter canopy structure. The canopy opens when the trees are top-killed; smaller lodgepole pines and regeneration of later successional species are then released (Peterson 1962; Krebill 1967).

Comandra blister rust is a native rust fungus that requires two different hosts to complete its life cycle, bastard toadflax (*Comandra umbellata*) and hard pines such as

lodgepole and ponderosa pines. The spores are spread by wind from the Comandra plants to infect pine needles and new shoots. The fungus then grows into the branch, creates a canker that kills the branch. These cankers often produce spores that appear as rust-colored blisters; these spores travel from the pine to infect the Comandra plant. As the fungus grows in the tree branch, it will advance towards the tree stem. If the fungus forms a girdling canker on the stem then the distal portion of the tree dies causing top-kill (Mielke 1957).

Growth stops for the top-killed tree unless it can grow a new top (Geils and Jacobi 1993). Sometimes a lower branch beneath the canker assumes terminal dominance and grows a new top. This new top helps the tree to start growing again, yet it appears as a fork or crook, which may reduce timber quality. New tree tops are only effective for a few years. The girdling stem cankers that originally caused top-kill continue to advance, regirdle the stems, and cause top-kill a second time (Geils and Jacobi 1993). Depending on tree size and site quality, the tree may live several more decades before succumbing to the disease or being killed by another mortality agent.

These spike-top trees have several disadvantages for forest management. Declining top-killed trees continue to use site resources and prevent healthier, younger trees from vigorous growth. The top-killed stem portion may become a fuel ladder for low intensity fires to climb into the canopy and become wildfires. Tree spike-tops are also less marketable for timber and create aesthetically unattractive landscape views.

Younger trees stand a greater chance of infections developing into stem cankers (Johnson 1979). While younger trees have less crown to be exposed to rust spores and have had less time of exposure, when a successful spore infection does occur on young tree foliage then this new infection may quickly develop into a girdling branch canker. A small branch may also be within close proximity to the tree's main stem and so this girdling branch canker may develop into a stem canker. If the tree is small enough, then the stem canker will successfully girdle the stem. Being a small tree, the amount of top-kill caused by the girdling stem canker will be more detrimental to the survival of the young tree than a girdling stem canker for a large tree (Geils and Jacobi 1990).

Comandra blister rust is widespread in the Western U.S. and occurs in about 25 percent of Wyoming's lodgepole pine stands (Andrew and Harrison 1959). This disease may have occurred at low levels throughout the 19th century. It appears to have dramatically increased from 1910 to 1945 due to unusual warm, moist, summer fronts (Krebill 1965). Lodgepole pine stands have increased in tree density and competition due to fire suppression. This has created a larger food base for the rust fungus with less vigorous trees to tolerate/resist the disease.

Current management for this disease is to reduce the disease incidence in lodgepole pines stands rather than trying to prevent the disease. Control of the alternate host plant, Comandra, is not feasible. Since the infection levels of the disease are already high in Wyoming and the spores are spread by the wind, most lodgepole pine in the analysis area has a great chance of being infected.

Heavily infected stands ought to be harvested as soon as management permits. Past studies in other forests in Wyoming have found that the trees are top-killed at about 80 to 90 years of age. Trees with multiple cankers, cankers in the lower third of the live crown, or with half of the crown top-killed ought to be removed during selective cuttings (Johnson 1986a). Sometimes cankers may be pruned from high-value trees.

If lodgepole pine is to regenerate a harvested site, then the stand should be overstocked since losses will occur due to the rust. Seed trees that remain should be free of the disease to lower incidence on the site and also possibly regenerate trees that have a higher tolerance to the disease (Johnson 1986a). If site quality is poor, intensive management should focus on mitigating as much disease damage as possible.

White Pine Blister Rust

White pine blister rust (*Cronartium ribicola*) infects limber pine trees on the Bighorn National Forest. The rust fungus also infects alternate hosts of currant or gooseberry plants (*Ribes* spp.) to complete its life cycles. The fungal spores spread by wind from the *Ribes* plants to infect pine needles. After a short infection time, the fungus will develop cankers that girdle and kill branches and eventually stems. Around the edges of these cankers, the fungus produces blisters of spores that travel by wind to infect the *Ribes* plants. While spores from *Ribes* can travel a great distance and still be viable, we find most pine infections in Wyoming occur in areas where *Ribes* plants grow in close proximity to the trees (Mielke 1943).

White pine blister rust has been very damaging to limber pine stands in Wyoming (Kendall and Schirokauer 1997). Current monitoring studies are being done on the Bighorn National Forest to evaluate disease spread and infection levels. The only control for this disease consists of cutting infected trees for sanitation purposes.

Dwarf Mistletoe diseases

Dwarf mistletoe is a parasitic plant that attacks conifers throughout the western U.S. (Hawksworth and Johnson 1989). The Bighorn National Forest has two species of dwarf mistletoe: *Arceuthobium americanum* on lodgepole pine and *A. cyanocarpum* on limber pine.

The parasite spreads to nearby trees by dispersing seeds that land on the needles of lodgepole pines. The seed grows into the tree's xylem and slowly develops an endophytic system along the tree branch to absorb water and nutrients from the tree. In the early stages of infection, these infected branches may appear swollen or cankered.

Three to four years after infection, the dwarf mistletoe will produce male and female aerial shoots. These shoots are small, pale green, and leafless. The male shoots produce staminate flowers, which release pollen. The female's shoots have pistillate flowers that develop into seeds shortly after pollination. After seed or pollen dispersal,

the terminal portion of the shoots wither and fall from the host tree. The residual shoots remain to produce a new seedcrop the next year (Hawksworth and Johnson 1989).

Dwarf mistletoe spreads to nearby trees by discharging its seeds up to 50 feet from the host tree. Sometimes the seeds will reinfect the same tree especially if the seed-bearing shoots are produced in the top of the tree. However, spread usually occurs from overstory to understory trees. Occasionally, the seeds can be spread long distances by wildlife that come into contact with the seeds.

Infected branches produce excessive, abnormal branching in the form of witch's brooms. The branches and infected stems may have swellings and cankers that develop which can be entry sites for other decay fungi. In time, the stem cankers girdle the tree and cause top-kill. Eventually, the parasite kills the trees unless it succumbs to other mortality agents first. Insects, particularly bark beetles, may cause an earlier death by attacking weakened heavily infected trees (Johnson et al. 1979; Tkacz and Schmitz 1986).

Dwarf mistletoe affects forest management in other ways besides causing tree mortality. Tree growth is greatly reduced by dwarf mistletoe infection. Studies have shown that dwarf mistletoe infected trees had less radial increment growth than uninfected trees (Myers et al. 1971). The disease often makes sites appear to be poor quality, but in reality, the dwarf mistletoe is slowing tree growth not the quality of the site. The disease also lowers timber quality, reduces seed production, and makes trees more susceptible to root disease and insect attacks. Visual quality is also reduced with increases in spike-tops and witches brooms. Wildfire susceptibility increases in severely infected stands. The witch's brooms and the top-killed trees create fuel ladders for low intensity ground fires to climb into the canopy becoming high intensity wildfires.

The disease spreads slowly, about 1-2 feet per year in even aged stands. Uneven-aged stands will have a greater spread and seeds fall from the infected overstory to the understory trees. Selective cutting has perpetuated this disease. Infected trees along visual and wildlife corridors have increased disease spread. Reduced clear cutting and small harvest units (less than 20 acres) have contributed to increased spread from infected forest stand edges.

Fires used to sanitize areas of dwarf mistletoe by destroying heavily infested stands. Dwarf mistletoe brooms allow low intensity ground fires to climb into the crowns of the trees and create crown fires that not only destroy the tree, but also the dwarf mistletoe parasite. With fire suppression, dwarf mistletoe incidence and severity increased in forest stands. Today, prescribed fires that destroy most of the stand could be used to clean up heavily dwarf mistletoe infested stands and allow uninfected tree regeneration to colonize the site (Zimmerman et al. 1988).

The dwarf mistletoe infection on the Bighorn National Forest occurs in over 36 percent of the lodgepole pine acreage. Suppression programs could be done on the Bighorn National Forest to reduce the impacts of this disease (Johnson 1986b).

Effective controls and suppression for dwarf mistletoe can be handled silviculturally. The parasite requires a living host; when the trees are cut then the parasite dies. The dwarf mistletoe is specific to a tree species; favoring another tree species will reduce the parasite on the site. The mistletoe spreads slowly and clear cuts will prevent its spread into uninfected stands. Dwarf mistletoes have long life cycles so infected seed trees may be used to restock a site if the seed trees are removed within about ten years. The disease is easy to detect and rate which can help in making management decisions for a site. Presuppression surveys can help define areas that need treatment.

Silvicultural treatments can be designed to use natural and artificial barriers such as ridgetops, roads, and creeks to prevent dwarf mistletoe seed dispersal (Dooling and Brown 1976). Wider clear cuts that avoid long, narrow strips so that an edge-effect is reduced may prevent dwarf mistletoe spread into new stands (Hawksworth 1958). Shelterwood and seed tree cuts may also be used if the infected overstory can be removed within ten years. Sanitation-thinning may be used when a stand is lightly infected. This kind of thinning works well if the stand dwarf mistletoe ratings are 1 or 2; all infected overstory and understory trees are felled. Replacing the stand is recommended for heavily infected stands with dwarf mistletoe ratings of 3 or greater (Hawksworth and Johnson, 1989). In Wyoming, dwarf mistletoe also has an elevational limit that is up to 500 feet below the elevation of lodgepole pine. The disease may be absent in the elevational difference and may allow more management alternatives (Dooling and Brown 1976).

There are several benefits for doing dwarf mistletoe suppression. Dwarf mistletoe slows down rotation age and reduces timber quality. An expense for site preparation, tree planting, and thinnings are worthwhile when dwarf mistletoe spread into healthy stands is prevented. Uninfected stands will be more productive and meet greater timber targets. The stands will be less susceptible to wind damage, fire, and insect/disease activities. Future rotations will be less likely to become infected with dwarf mistletoe disease.

Management decisions for dwarf mistletoe control should be based on individual site conditions. Stand composition, density, disease incidence, and severity will all play a role in future management plans. Available stand growth and dwarf mistletoe infection models may help in determining these management plans.

Needlecast diseases

Lophodermella spp. needlecast disease outbreak occurred on lodgepole pine of the Bighorn National Forest in the early 1990's (Pasek 1993). The needlecast disease was found on over 12,000 acres on the Bighorn National Forest but remained at outbreak levels for only 2 - 3 years.

Currently, the limber pine on the forest may be experiencing a widespread needlecast disease outbreak. Limber pine stands have been noticed to be declining in Wyoming

and Montana. In Montana, *Dothistroma septospora* needlecast disease has been identified as a major contributor to this decline (Taylor and Schwandt 1998). It is possible that this disease is also active in the Bighorn National Forest.

Infection by these needlecast fungi occurs in the spring and symptoms of reddish brown needles become apparent in the autumn or following spring. The fungi are usually identified by their small, elliptical, dark fruiting structures formed on the needles. The needles are soon cast from the tree and repeated defoliation over a few years may cause mortality.

Forest management in areas with high needlecast disease problems should focus on favoring apparent resistant tree individuals. Since the needlecast diseases are found on the pines in the Bighorn Mountains, then other tree species may be favored in these areas (Johnson 1985).

METHODS

Staff from the Rapid City Forest Health Management Service Center conducted a survey for possible damaging insects and diseases across a large portion of the Bighorn National Forest. Because a biological evaluation was completed for the Little Bighorn Analysis Area in 1998 (Harris et al. 1998), the current evaluation excluded the Little Bighorn area. The survey's emphasis was especially focused on bark beetles of spruce, fir, and pine, rust diseases, and dwarf mistletoe diseases.

Chain-wide survey transect lines were traversed to detect and evaluate the insects and disease pathogens of the forested area. Two- or three-person crews surveyed 17.5 miles divided among 31 transects to detect insect and disease activity by two different methods. First, dying or recently dead trees were examined for bark beetle activity along the transects. Second, dwarf mistletoe and rust diseases were evaluated in variable-radius plots installed every 10 chains along the transect lines. A transect was considered to be lodgepole pine forest-type if more than 50 percent of trees in the variable-radius plots were lodgepole pine or spruce-fir forest-type if more than 50 percent of trees in the variable-radius plots were spruce-fir

While traversing the transect lines, any dying or recently dead trees (trees with yellow or red foliage) were examined for beetle or root disease activity. Counts were made of the various bark beetle attacked-trees along each transect. If root diseases were found, then they were identified and their location was noted during the survey.

Variable-radius plots, used for rust and dwarf mistletoe disease evaluations, were based on a basal area factor "20". These plots were installed every 10 chains along each transect. All trees in the variable-radius plots were evaluated for:

- Species;
- Size Class - seedling, sapling, pole, and sawtimber;
- Health Status - healthy = no defects or injuries, declining = 1 major or 3 minor injuries, dying = 2 or more major injuries, recently dead, long dead;
- Dwarf Mistletoe - the Hawksworth 6-class dwarf mistletoe rating system
- Comandra Blister Rust - a 5-class rating system was used. 0 = no rust infection, 1 = branch canker, 2 = stem canker with no top kill, 3 = stem canker with top kill, and 4 = tree mortality.

The survey data for transects were analyzed by counts and averages for the forest stand conditions and the various insects and diseases. Average diameter at breast height (DBH) and basal areas were calculated for each of the survey transects. Bark beetle-killed trees per acre were calculated. Because tree age and elevation by plot was not known, mountain pine beetle risk rating was not possible for stands of lodgepole pine. Therefore, qualitative estimates of risk were made using only average DBH of lodgepole pine and latitude. Counts of healthy and infected lodgepole pine were recorded, and averages of disease ratings were calculated for the infected lodgepole pine. White pine blister rust disease was evaluated using the same rating system as for Comandra blister rust.

In addition to the transect surveys, mountain pine beetle was evaluated along the east slope of the Bighorn National adjacent to Highway 14. This area was primarily comprised of ponderosa pine with scattered Douglas-fir and limber pine. Two separate sites (near Steam Shovel Draw, Crystal Springs scenic overlooks) were surveyed for current and previous infestations.

SURVEY RESULTS AND DISCUSSION

Forest Stand Conditions

For the areas of the Bighorn National Forest that were surveyed, forested stands were primarily comprised of pure lodgepole pine stands or mixed stands spruce, fir, and pine (Table 1). However, two transects conducted within the Ten Sleep Canyon contained limber pine and Douglas-fir. Trees across all stands averaged greater than 10.8 inches DBH and stand densities averaged 162 square feet/acre BA. The major species components had an average DBH of 9.2 (lodgepole pine), 15.2 (Engelmann spruce), 9.4 (subalpine fir) and 12.2 (limber pine). Minor components included areas of quaking aspen at higher elevations and Rocky Mountain juniper in lower elevations.

Table 1. Summary of forest type and transects surveyed in the Bighorn National Forest.

Transect	Acres	Basal Area	DBH	%LPP[1]	%ES[2]	%SAF[3]	%LP[4]	%DF[5]
Spruce-fir type								
Hwy 14A & FS10	4	160	16.0	0.0	75.0	25.0	0.0	0.0
Bull Creek	4	180	10.1	0.0	71.4	28.6	0.0	0.0
FS170 & FS169	1	140	9.7	28.6	28.6	42.8	0.0	0.0
FS215	4	205	10.4	17.5	60.0	22.5	0.0	0.0
FS176	4	185	13.6	8.3	61.1	30.6	0.0	0.0
FS281 & FS26	4	205	13.2	12.5	87.5	0.0	0.0	0.0
FS10 & Hwy 14A	4	155	14.9	0.0	80.0	20.0	0.0	0.0
Woodchuck Run	4	220	14.7	27.9	65.1	7.0	0.0	0.0
FS221 North	4	200	17.2	0.0	84.6	15.4	0.0	0.0
FS221 South	4	230	18.6	0.0	81.8	18.2	0.0	0.0
Lodgepole type								
Coney Creek TH	4	170	10.2	78.8	15.2	6.0	0.0	0.0
Ranger Creek Rd	4	125	11.7	95.8	0.0	4.2	0.0	0.0
FS 312	4	150	6.9	100	0.0	0.0	0.0	0.0
FS159	4	175	9.9	82.4	17.6	0.0	0.0	0.0
FS26	4	175	8.1	100	0.0	0.0	0.0	0.0
Coney Creek # 2	4	145	10.3	78.6	10.7	10.7	0.0	0.0
FS313 & FS26	4	195	7.9	97.4	0.0	2.6	0.0	0.0
Sheep Mountain	4	150	10.7	82.4	10.3	6.9	0.0	0.0
FS27, Tyrell WC	4	125	9.2	100	0.0	0.0	0.0	0.0
Arrowhead Lodge	8	137.5	11.1	86.9	9.3	1.9	0.0	0.0
FS519 & FS26	3	106.7	6.1	100	0.0	0.0	0.0	0.0
FS26 North	12	145	11.3	80.3	17.4	2.3	0.0	0.0
Sucker Creek	4	140	10.9	85.2	14.8	0.0	0.0	0.0
Hunter Corral	4	170	6.3	100	0.0	0.0	0.0	0.0
FS396	4	165	8.2	100	0.0	0.0	0.0	0.0
FS21	8	145	7.4	100	0.0	0.0	0.0	0.0
Doyle Campground	4	187.5	9.9	100	0.0	0.0	0.0	0.0
FS506	8	177.5	8.9	100	0.0	0.0	0.0	0.0
Loaf Mtn Overlook	4	190	7.4	100	0.0	0.0	0.0	0.0
Limber pine type								
Ten Sleep 1	4	100	11.2	0.0	0.0	0.0	84.2	10.5
Ten Sleep 2	4	65	13.2	0.0	0.0	0.0	66.7	25
Mean	**4.52**	**161.8**	**10.8**	**60.1**	**25.4**	**7.9**	**4.9**	**1.1**
SD	**1.95**	**35.8**	**3.1**	**43.3**	**32.8**	**11.6**	**19.0**	**4.8**

[1] Percentage of transect that was lodgepole pine. [2] Percentage of transect that was Engelmann spruce.
[3] Percentage of transect that was sub-alpine fir. [4] Percentage of transect that was limber pine.
[5] Percentage of transect that was Douglas-fir.

Insects

Bark beetle activity within the analysis area is summarized in Table 2. Western balsam bark beetle-disease complex and spruce beetle caused most of the damage in the spruce-fir forest type. Stable or declining populations of western balsam bark beetle were observed based on the number subalpine fir killed in 1998 and 1999. This level of activity should be considered below outbreak level. Approximately the same level of current spruce beetle activity was found as western balsam bark beetle. Higher levels of western balsam bark beetle were found in the Little Bighorn Analysis Area evaluated in 1998 (Harris et al. 1998). The higher proportion of spruce-fir in that area may have contributed to the higher the level of activity. Although the level of spruce beetle activity was at endemic levels, there were some moderately large pockets of spruce mortality within the study. The spruce-fir stands within the area should be considered high risk because of the large diameters, high proportion of spruce-fir, and relatively high stand densities (Table 1).

Mountain pine beetle and Ips pine engraver activity was also low within the lodgepole forest type. Less than 1 tree killed per acre is considered an endemic level. Based on tree diameter, latitude, and approximate elevation data collected from the cruise lines, lodgepole pine stands ranged from high (e.g., Ranger Creek Road transect) to low (e.g., FS312 transect) risk. Average diameter for lodgepole pine trees measured within the study area was 9.2 inches (Table 1). Obviously, stands consisting predominantly of regeneration will have lower DBH and be of less risk to pine beetle outbreak. Lodgepole pine stands at relatively lower elevations (e.g., <7,500 ft.) are higher risk than stands at high elevation (e.g., >8,500 ft.) for a latitude of $44^0 5'$ N.

Several small to medium sized pockets of beetle activity were recorded in the ponderosa pine stands adjacent to Highway 14 along the east slope of the Bighorn Mountains (Table 3). Based on this limited sampling, there was a stable to increasing population of beetles in this area. Much of this area can be characterized as highly susceptible to beetle attack, with large diameter trees in primarily dense, pure stands of ponderosa pine.

Although the average DBH of limber pine in the Ten Sleep Canyon area was greater than 12 inches, the basal areas were comparatively low (Table 1). In spite of the low basal areas, mountain pine beetle was found to be active throughout the area (Table 2). Perhaps mountain pine beetle was attacking the limber pine in this area in response to the trees being stressed by white pine blister rust infections, or perhaps limber pine susceptibility is independent of basal area.

Douglas-fir was a minor component in the area evaluated and, therefore, Douglas-fir beetle was not documented. However, based on past activity in the area, Douglas-fir beetle can be a problem in multi-storied stands of Douglas-fir and in Douglas-fir stands affected by blowdown or fire scorch.

Table 2. Summary of trees killed per acre by western balsam bark beetle (WBBB), spruce beetle (SB) and mountain pine beetle or Ips (MPB/Ips) in the area surveyed of the Bighorn National Forest. Mean (± Standard Deviation) are shown in bold for forest type and overall transect summary.

Transect	WBBB		SB		MPB/Ips		Total		
	1999	Old	1999	Old	1999	Old	1999	Old	Total
14A & FS10	0.25	1.25	0.75	6.25	0.0	0.0	1.0	7.5	8.5
Bull Creek	1.0	2.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0
FS170	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FS215	1.25	1.5	0.75	0.0	0.0	0.0	2.0	1.5	3.5
FS176	2.25	1.25	1.0	0.0	0.25	0.0	3.5	1.25	4.75
FS281	0.25	0.0	0.5	0.5	0.0	0.0	0.75	0.5	1.25
FS10 & 14A	2.0	2.0	0.25	1.0	0.0	0.25	2.25	3.0	5.25
Woodchuck	0.0	1.5	1.5	2.0	0.0	1.25	1.5	3.75	5.25
FS221 N	0.5	1.25	1.25	5.75	0.0	0.0	1.75	7.0	8.75
FS221 S	0.0	0.0	1.0	1.5	0.0	0.0	1.0	1.5	2.5
Spruce-fir	**0.75**	**1.08**	**0.70**	**1.70**	**0.06**	**0.06**	**1.48**	**2.80**	**4.28**
Mean/SD	**0.84**	**0.79**	**0.51**	**2.37**	**0.08**	**0.06**	**0.97**	**2.59**	**2.84**
Coney Cr.	0.0	0.0	0.0	0.0	1.0	2.0	1.0	2.0	3.0
Ranger Cr.	0.0	0.0	0.0	0.0	0.0	3.25	0.0	3.25	3.25
FS 312	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FS159	0.0	0.0	0.0	0.0	0.75	0.0	0.75	0.5	1.25
FS26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coney Cr. 2	0.0	0.0	0.0	0.0	0.25	0.0	0.25	0.0	0.25
FS313	0.0	0.0	0.0	0.0	0.25	0.25	0.25	0.25	0.5
Sheep Mtn.	3.0	0.5	0.0	0.0	0.5	0.0	3.5	0.5	4.0
Tyrell WC	0.0	0.0	0.0	0.0	0.25	6.25	0.25	0.0	0.25
Arrowhead	0.13	0.0	0.5	0.63	2.63	0.33	3.25	6.88	10.13
FS519	0.0	0.3	0.0	0.0	0.0	0.25	0.0	0.67	0.67
FS26 North	0.17	0.0	0.25	0.17	0.25	1.5	0.67	1.42	2.08
Sucker Cr.	0.0	0.0	0.25	0.0	0.25	0.0	0.5	1.5	2.0
Hunter Corral	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FS396	0.0	0.0	0.0	0.0	0.25	0.0	0.25	0.0	0.25
FS21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Doyle Camp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FS506	0.0	0.0	0.0	0.0	0.13	0.0	0.13	0.0	0.13
Loaf Mtn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lodgepole	**0.17**	**0.04**	**0.05**	**0.04**	**0.34**	**0.81**	**0.57**	**0.89**	**1.46**
Mean/SD	**0.69**	**0.13**	**0.13**	**0.15**	**0.24**	**0.42**	**1.03**	**1.70**	**2.45**
Ten Sleep 1	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.25	1.25
Ten Sleep 2	0.0	0.0	0.0	0.0	2.25	0.0	2.25	0.0	2.25
Limber pine	**0.0**	**0.0**	**0.0**	**0.0**	**1.63**	**0.13**	**1.63**	**0.13**	**1.75**
Mean/SD	**0.0**	**0.0**	**0.0**	**0.0**	**0.88**	**0.18**	**0.88**	**0.18**	**0.71**
Overall Mean	**0.35**	**0.37**	**0.26**	**0.57**	**0.32**	**0.52**	**0.93**	**1.46**	**2.39**
SD	**0.76**	**0.66**	**0.45**	**1.64**	**0.46**	**0.34**	**1.08**	**2.16**	**2.80**

Table 3. Summary of ponderosa pine attacked by mountain pine beetle in areas surveyed adjacent to Highway 14 on the Bighorn National Forest.

Site	1999 Infested	1998 Infested	Old Infested	Total Infested
Steam Shovel Draw 1	2	37	9	48
Steam Shovel Draw 2	20	8	7	35
Crystal Springs 1	9	4	2	15
Crystal Springs 2	58	30	2	90
Total	**89**	**79**	**20**	**188**

Diseases

Armillaria root disease was not detected in any transect even though pockets of the root disease occur in the analysis area. If forest managers need more information about the distribution of this root disease, further survey work will be needed. A root disease survey for Annosus root disease may also help forest managers with areas of sub-alpine fir decline due to root disease.

Similarly, we did not record any incidence of needlecast diseases in the areas surveyed.

Of the lodgepole pine surveyed in the variable radius plots along transects, more than 38 percent were infected with either Comandra blister rust and/or dwarf mistletoe diseases. Only 1.7 percent of the lodgepole pines surveyed had both diseases. Eight percent were infected with only Comandra blister rust disease and another 28 percent were infected with dwarf mistletoe disease only (Figure 1).

The Comandra blister rust incidence on lodgepole pine in the survey area was moderate with 8 percent of all lodgepole pine trees infected with the rust (Table 4). Infected trees had a 3.3 average severity rating. This severity rating indicates that these lodgepole pine trees have girdling cankers in the middle section of their crowns or non-girdling cankers in the lower portions of the crowns. For trees with girdling cankers, this rating indicates that a large portion of the crown is top-killed and the trees are in a serious state of decline. Trees with non-girdling cankers in the lower crown may soon be top-killed as the cankers grow towards and girdles the stem. These trees are not growing and yet will continue to use valuable site resources for possibly several more decades reducing the vigor of surrounding, competing trees.

White pine blister rust was confirmed on several limber pines in Ten Sleep Canyon. Approximately 36 percent of the limber had signs of rust infection (table 4). Significant branch mortality was observed and in some cases tree mortality. While the disease has great potential to decimate limber pine, in this area it seems to be at a moderate incidence level. Further monitoring of this disease needs to be conducted over several years to determine the rate of infection and intensification.

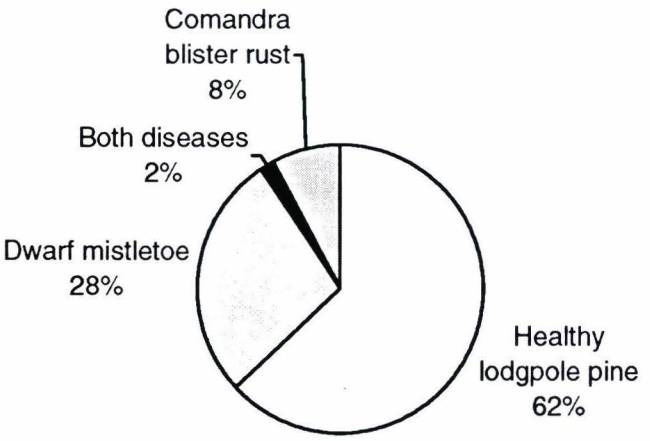

Figure 1. Percent of lodgepole pine infected with dwarf mistletoe and Comandra blister rust in the surveyed areas of the Bighorn National Forest.

The average dwarf mistletoe rating for all the dwarf mistletoe infected trees was 2.6 (Table 4). The average dwarf mistletoe rating for all lodgepole was less than 1. These ratings indicate that the disease was at a medium level of infection on the diseased trees. The disease will continue to progress in these trees, spread to nearby lodgepole pines, and reduce growth and vigor on the site. Some of the trees did have high dwarf mistletoe ratings and will die within a few years. Suppression efforts in some of the more heavily infected stands may be able to reduce the disease and encourage a healthy stand on the site.

Dwarf mistletoe incidence on lodgepole pine for the Bighorn National Forest was reported as 36.5 percent of acres surveyed (Johnson, 1979). The current survey was less with approximately 28 percent infection among all lodgepole pine (Table 4). Perhaps this difference was caused by different methods used for surveying and analysis. This lower dwarf mistletoe incidence may also have been caused by a large number of spruce-fir type and limber pine-type sites found during the survey. However, some transects did have a high percentage of trees infected (e.g. transects near FS313, FS396 and Doyle Campground). The spread of dwarf mistletoe is gradual and slow, and unless a stand or plot is near infected trees then it will probably not be infected.

Severity ratings for dwarf mistletoe were calculated by averaging all infected trees of the variable radius plots. While clear cuts or stand-replacing fires are the recommended treatments for stands with high dwarf mistletoe ratings (DMR>3.0), stands with lower ratings may be able to use a variety of selective cuts.

Table 4. Summary of dwarf mistletoe ratings (DMR) and Comandra blister rust incidence on lodgepole pine (LPP) on the Bighorn National Forest. Only transects that had greater than 50 percent lodgepole pine or limber pine are shown.

Transect	% DMR[1] LPP	Ave DMR[2]	DMR all[3]	% Rust LPP[1]	Ave Rust[2]	Rust all[3]	% DMR + Rust[4]
Lodgepole pine type							
Coney Creek	3.7	2.00	0.07	22.2	3.7	0.74	0.0
Ranger Creek	29.2	4.90	1.42	20.8	3.6	0.75	4.2
FS312	12.0	2.30	0.30	21.7	3.6	0.75	0.0
FS159	0.0	--	0.00	3.4	4.0	0.14	0.0
FS26	11.8	1.25	0.14	2.9	3.0	0.09	0.0
Coney Cr. # 2	4.3	2.00	0.09	13.0	2.0	0.26	0.0
FS313	73.7	3.64	2.68	26.3	3.1	0.82	18.9
Sheep Mtn.	28.0	3.40	0.96	4.0	4.0	0.16	0.0
Tyrell WC	12.5	1.30	0.16	0.0	--	0.00	0.0
Arrowhead Lodge	23.4	3.36	0.77	4.3	3.5	0.15	0.0
FS519	53.3	4.75	2.38	0.0	--	0.00	0.0
FS26 North	36.2	3.64	1.30	13.0	3.5	0.10	4.3
Sucker Creek	26.0	1.50	0.38	0.0	--	0.00	0.0
Hunter Corral	38.2	2.08	0.79	0.0	--	0.0	0.0
FS396	81.8	3.15	2.57	9.1	3.7	0.3	3.0
FS21	43.1	2.32	1.00	1.7	4.0	1.0	0.0
Doyle Camp	60.6	2.43	1.50	6.1	3.5	0.2	3.0
FS506	5.6	1.50	0.10	1.4	2.0	0.1	0.0
Loaf Mtn	2.6	1.00	0.03	2.6	2.0	0.1	0.0
Mean	**28.74**	**2.58**	**0.88**	**8.03**	**3.28**	**0.26**	**1.76**
SD	**24.66**	**1.17**	**0.89**	**8.78**	**0.72**	**0.29**	**4.43**
Limber pine type							
Ten Sleep 1	--	--	--	5.9	2.0	0.11	--
Ten Sleep 2	--	--	--	66.7	1.5	1.00	--
Mean	**--**	**--**	**--**	**36.3**	**1.75**	**0.56**	**--**
SD	**--**	**--**	**--**	**43.0**	**0.35**	**0.63**	**--**

[1] Percent of lodgepole pine with dwarf mistletoe rating, Comandra blister rust or white pine blister rust.

[2] Average dwarf mistletoe rating, Comandra blister rust or white pine blister rust of infected trees only.

[3] Average dwarf mistletoe rating, Comandra blister rust or white pine blister rust for all pine.

[4] Percent of lodgepole pine that were infected with both dwarf mistletoe and Comandra blister rust.

RECOMMENDATIONS

The following are our recommendations for management of forested areas within the Bighorn National Forest to increase the overall health of the forest. Management should try and simulate the natural disturbance processes that have shaped this area over time while meeting the desired objectives of this area. The most common disturbance agents in this area include fire, insects and diseases, and windthrow events.

1. Spruce/fir - Use of stand replacing fire/overstory removal/group selection cuts.

The spruce/fir type in much of this area seems to be mature to overmature and needs to be regenerated. There is a considerable amount of "fir decline" throughout the forest in areas that are predominantly spruce-fir, and although the causes are not specifically known, at least a part of the problem could be related to an increase in overmature fir stands. The use of stand replacing fires in spruce/fir should return the area to an earlier successional stage, perhaps in some places even regenerating additional lodgepole pine stands. Stand replacing fires could be used to take out the declining stands.

The use of low intensity fires to remove understory vegetation is not recommended. Fires would have to be executed cautiously, as fire-scorched spruce trees can be highly attractive to spruce beetles, leading to a buildup in population and beetles killing remaining green trees. Many of the spruce/fir stands have high basal areas that mainly consist of large diameter spruce trees. These conditions are highly favorable for sustaining an outbreak of spruce beetle should one get started.

The use of small group selection cuts should be considered in much of the spruce/fir type. This would create openings to regenerate the stands and also provide fire breaks in the landscape that could be used in following stand replacing burns. There is also the opportunity for doing some overstory removal in spruce /fir stands. Many of these stands already have considerable regeneration in the understory, removal of the overstory would decrease the stand susceptibility to beetle attacks while releasing the understory. If overstory removals are done, stands should be monitored for root diseases, which could build up in large cut stumps and attack regeneration.

A major concern that would need to be addressed in any manipulation of spruce/fir stands is the problem of windthrow. The Bighorn National Forest seems to have frequent wind events that end in some levels of windthrow, particularly in the spruce/fir type. Windthrown trees can be used by spruce beetle to buildup and then infest standing, green trees. How western balsam bark beetle responds to windthrow trees is unknown at this time. Any treatment, either fire or silvicultural treatments, where the desired condition was to leave much of the surrounding overstory, would have to consider and take actions to reduce the possibility of windthrow.

Should windthrow events occur in these stands, prompt salvage of as much of the down material as possible is warranted. This should help reduce the chance of beetle buildup in this material if it is salvaged in the first 2-3 years after windthrow.

2. Douglas-fir type - Use of prescribed fires/thinning.

In the stands predominated by Douglas-fir, the use of low intensity ground fires can help maintain them. Without disturbance in these areas, they become multi-storied. The understory, typically of Douglas-fir, provides very good habitat for western spruce budworm to build up and sustain outbreaks. The Douglas-fir beetle often follows stress events, such as budworm outbreaks, and can build up and kill green trees. Use of fire or thinning from below can remove this lower level, making these areas much less suitable for budworm.

However, the use of fire should be done carefully if maintenance of the overstory is desired. The Douglas-fir beetle can also be attracted to trees that have been fire scorched, but not killed. The beetle can build up in these scorched trees and then spread to nearby green trees. It can lead to impressive outbreaks and a high level of mortality in larger overstory trees. This has been the scenario that came to pass on the Shoshone National Forest over the last 10 years following the Yellowstone fires; Douglas-fir beetle built up in scorched trees and proceeded to move to standing green trees. In some of these areas, it may be best to thin from below prior to introducing fire to make sure that the fire intensity remains low.

In addition to seeking out stressed trees, the Douglas-fir beetle causes the most damage in stands that have a high percentage of the overstory in larger diameter Douglas-fir. In mature stands of Douglas-fir, thinning stands to lower the amount of mature Douglas-fir in the overstory will reduce the possibility of beetle outbreaks.

3. Lodgepole pine and Limber pine - Use of stand replacing fire/thinning/overstory removal.

The tactic to use in lodgepole pine and limber pine stands depends on the current conditions in a given stand. In pine stands that are heavily infected with dwarf mistletoe or rust disease, the use of high intensity, stand-replacing fires is appropriate. Stands that are heavily infected with mistletoe have historically been prone to these high intensity fires as a method of sanitizing the stand and regenerating a new stand. Less is known about the relationship between Comandra rust and fire, but many of these stands have become stagnant and a stand replacing fire may be the most cost efficient way to create healthier stands in the long-term. Stand replacing fires will also reduce the amount of encroachment from spruce/fir types into areas of pine.

In lodgepole pine stands where past management has occurred, incidence of mistletoe and Comandra was much lower than in areas where there had been no management. Our recommendation for areas where past management has occurred is to use timber harvest, in the form of overstory removal, clearcutting, small group or single-tree

selection or thinning, to maintain these stands in good condition. In areas where much of the overstory has been removed and there is an acceptable level of regeneration, overstory removals should be implemented to lower the chances of spreading mistletoe. In the younger stands, where there are low levels of mistletoe or Comandra, precommercial thinning or small group/single tree selection cuts that remove any currently infected trees is advised. In stands that are heavily infected throughout, clearcutting could be substituted for stand replacing fires if feasible.

Risk of lodgepole pine stands for having a mountain pine beetle epidemic start and be sustained will vary across the forest. Risk will go up or down depending on the elevation of the stands along with tree size and age. There is evidence that the beetle has been active across the forest in the past and caused a relatively large amount of lodgepole pine mortality. This suggests that the beetle is capable of causing considerable levels of damage. Beetle susceptibility throughout all areas of the forest can be decreased greatly by lowering the average diameter and tree age of lodgepole pine. Based on this assumption, any activities used to lower dwarf mistletoe or rust diseases would also lower susceptibility to mountain pine beetle.

The limber pine stands in Ten Sleep Canyon are moderately infected with white blister rust and also are being attacked by mountain pine beetle. Further monitoring of this disease needs to be conducted over several years to determine the rate of infection and intensification. The only control for this disease consists of cutting infected trees for sanitation purposes. Although no work has been conducted on silvicultural treatments for reducing beetle damage in limber pine, based on what is known from lodgepole and ponderosa pine, limber pine stands should be treated to remove the largest diameter trees and reduce stocking levels. Without any real information, these seem to be the safest options for minimizing beetle damage.

4. Ponderosa pine type - Use of thinning and prescribed fire.

In the ponderosa pine forest type, Douglas-fir is encroaching and becoming a larger part of the stand. Also, there are increasing mountain pine beetle populations in ponderosa pine forests along the east slope causing mortality. Both Douglas-fir encroachment and beetle infestations will continue to occur if no management actions are implemented.

In ponderosa pine stands where there Douglas-fir is encroaching, the use of low intensity ground fires, to kill some of the Douglas-fir understory would help reverse the trend and increase or at least maintain the ponderosa pine. Openings in the pine are going to be created by mountain pine beetle; there is already some beetle activity occurring at this time. Beetle activity will continue in this area over the next several years. The level of ponderosa pine mortality is difficult to predict, but most of the ponderosa pine along the east slope is highly susceptible to the beetle. Where possible, thinning ponderosa pine stands to lower their susceptibility to the beetle should be considered. In many places, commercial thinning may not be feasible due to unsuitable terrain. If beetle activity continues to increase, removal of infested trees in a sanitation activity, either commercial or non-commercial, may be appropriate.

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